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A COMPREHENSIVE REVIEW OF TECHNOLOGICAL INTERVENTIONS AND TRENDS IN INDIAN DAIRY FARMING

Dr. Shiv Shanker Katiyar
(Associate Professor)
Animal Husbandry & Dairying
R.S.M. College, Dhampur, Bijnor (U.P.)

Abstract

Indian dairy producers are smallholder farmers apart from the security of national nutrition, this is crucial for rural people's way of life as most. Mostly resulting from several technical developments meant to increase output, efficiency, and sustainability, the sector only recently underwent a major transformation. Covering precision dairy farming, automation (Dairy 4.0), artificial intelligence, machine learning, genetic enhancement, and innovation targeted on women, infrastructure improvements, and climate resilience, this review gives a whole summary of the most recent technical developments in Indian dairy farming. Scholarly literature and peer-reviewed studies in the paper show how long-standing issues including low milk output, disease outbreaks, inadequate supply networks, and gender inequality are being resolved by these technologies. The paper also underlines among other things infrastructure constraints smallholders have in using technology, digital literacy, and cost. This study intends to provide a plan for equitable and sustainable development in the Indian dairy industry combining modern technologies with traditional knowledge. Maintaining India's leadership position in dairy output, strategic investment, stakeholder participation, and inclusive policy frameworks helps India to concurrently advance environmental stewardship and economic empowerment.

Keywords: Dairy technology, Precision dairy farming, Genetic breeding, Climate resilience, Indian dairy industry

1. Introduction

India boasts the highest milk output and consumption worldwide; the dairy business mainly helps rural areas [1]. Usually running less than five cows, smallholders account for the majority of dairy output in India. Not too long ago, the Indian dairy sector saw a major transformation primarily in reaction to technological advancements updating traditional methods [2]. Combining creativity with agriculture has produced ideas designed to improve low output, animal health, and inadequate supply chains, as well as technologies [3]. The numerous technologies applied in Indian dairy farming enterprises and their influences on the direction of the sector are evaluated in this research. Front stages are precision dairy farming, automation, artificial intelligence, machine learning, genetic improvements, women-centric programs, infrastructural development, and sustainable practices [4].

India's rising milk output and consumption point to rural areas often benefiting the dairy businesses and to maintain less than five cows, smallholders are the principal producers of dairy products in India. The Indian dairy industry recently saw a major transformation largely coming from technological advancements updating traditional processes. Combining innovation with agriculture has generated concepts aimed to improve low output, animal welfare, and weak supply chains in step with technological developments. This research evaluates the several technologies applied in Indian dairy farming enterprises and their effects on industry development. Precision dairy farming, automation, artificial intelligence, machine learning, genetic developments, women-oriented programs, infrastructure building, and sustainable practices are key components. Along with technological developments, the Indian dairy company has observed increasing public agency cooperation and public agency investment for commercial agritech companies. Apart from digital extension services, farmers also get mobile veterinarian care, rapid treatment, feed management, and breeding support. These programs are closing the knowledge gap and allowing underprivileged farms to use data-informed decision-making tools. Mobile dairy consulting tools such as "Hello Poshan" and "Animal Health Bridge" are thereby so enhancing herd health and output by means of feeding regimens and real-time disease reporting [5].

Reacting to consumer demand for traceability and quality assurance, the sector has been pushing block chain and RFID-based monitoring technologies to raise milk supply chain openness [6]. These techniques seek to reduce adulteration, guarantee safety criteria, and improve export compliance. They also advocate conformity imports. Under worldwide concerns about sustainability and climate change, Indian dairy sector operators have changed feeding schedules, advocated climate-resilient fodder, and run renewable energy under on-farm operations [7]. Rising wealth, urbanization, and changing eating habits help India to show the dairy industry as a significant participant. Apart from raising output, technologically driven interventions would guarantee food security, change rural life, and help India to lead the world in ecologically friendly dairy operations [8]. This work aims to study, with extreme precision, the specific technical aspects enabling this transformation.

2. Precision Dairy Farming (PDF)

By introducing modern technologies permitting real-time monitoring and data-driven decision-making, Precision Dairy Farming (PDF) is revolutionizing dairy management. Here we track, record, and investigate notable traits of individual animals using wearable sensors, automatic milking systems, environmental monitoring tools, IoT-based platforms. This method enables farmers more precisely to manage early disease symptoms, reproductive cycles, and feeding patterns. Wearable sensors as pedometers and rumination collars can identify minute behavioural changes suggestive of health issues, therefore enabling quick intervention and reducing of financial losses. Consistent milking methods and less dependence on human labour enable automated systems increase milk quality and yield. One great benefit of PDF is its ability to increase resource economy. Precision feeding systems and other technologies ensure that every cow gets a customized diet depending on her physiological demand, therefore lowering feed waste and increasing nutrient absorption. By enabling one to regulate appropriate temperature and humidity, installable environmental sensors in barns improve animal comfort and wellbeing. In places with high temperatures, these advancements particularly benefit since little changes in the temperature can greatly influence animal output. Studies reveal that these technological developments can raise general farm profitability and enhance animal welfare in Indian dairy systems [9].

Although PDF has certain advantages, its general use in India creates significant challenges. Main initial investment costs, inadequate knowledge, and weak technical skills remain major obstacles especially for smallholder farmers. Moreover, poor digital infrastructure in rural areas lowers the real-time data processing and transmission, therefore lowering the efficiency of precision technology. Still, some much focused initiatives have great potential. Tamil Nadu Veterinary and Animal Sciences University (TANuvas) has produced more milk and lower disease incidence by means of sensor-based health monitoring systems [10].

Supportive regulations, instructional projects, and coordinated efforts among government agencies and commercial technology businesses will decide how Precision Dairy Farming grows in India. Public-private partnerships can significantly reduce costs and improve accessibility, even if government subsidies serve to relieve some financial burden on small farmers. Not less important is the need of thorough training courses providing farmers with the tools to apply and assess modern technologies. The experts assert, depending on proper handling of these obstacles, the introduction of precision technology can significantly boost India's dairy industry [11].

Automation and Dairy 4.0

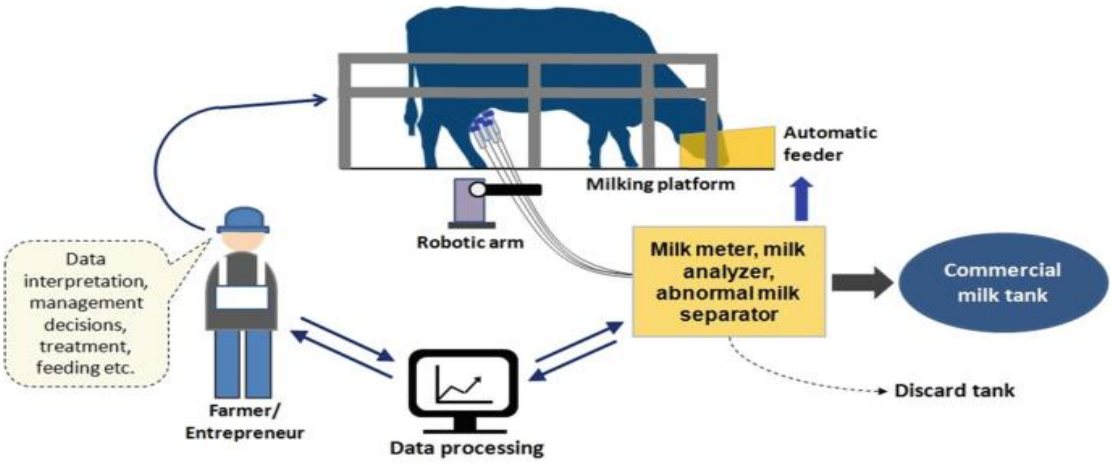

Fig 1: Automatic milking system [11]

Dairy 4.0 supports the use of digital technology and automation inside the dairy value chain, therefore fitting the more generally Industry 4.0 idea. This affects smart cooling design, robotic feeders, and automatic milking systems (AMS). Automation promises higher running efficiency, lower need for hand labour, and hygienic standards. Although most Indian small-scale farmers function totally under automation, their use is somewhat limited. Large cooperatives and dairy farms are starting to employ robotic milking systems since they save human mistake and milking time. Research by Jacobs and in the Journal of Dairy Science show via constant and moderate milking that AMS can improve udder health and increase milk output consistency. Customized feed programs based on individual animal profiles enable smart feeding systems to maximize nutrient absorption and hence lower waste. Mark still another important step: the automated milk collecting units (AMCUs), which ensure on-site milk fat and SNF level measurement as well as payment transparency. Real-time recording and connection with digital payment systems helps one to become accountable. For smaller producers, early costs and infrastructure are problems; government subsidies and cooperative structures help to enable more general access. Applied strategically, automation offers great potential to increase the sustainability, efficiency, and quality of dairy production [12].

2. Artificial Intelligence (AI) and Machine Learning

Rising as transformative technologies in the Indian dairy industry, artificial intelligence (AI) and machine learning (ML) provide predictive modelling and data-driven decision-making. These gadgets understand animal health, reproductive activity, and environmental variables using massive databases created from sensors, cameras, and hand-activated inputs. Gait and posture are assessed using artificial intelligence methods including computer vision, which also helps in early stage lameness or disease diagnosis. Using milk conductivity and temperature data, machine learning techniques can predict mastitis, therefore improving early identification and lowering treatment costs. [13] artificial intelligence-based mastitis detection systems were more sensitive and specific than more traditional approaches. Using real-time

data inputs, Agritech develops smartphone apps including MooON and BharatAgri with particular guidance on feeding strategies, immunizations, and reproductive control. Underlining supply chain optimization is route planning for milk collecting paired with artificial intelligence and demand forecasting. These qualities provide minimal running costs, fast delivery, and assist to stop rotting. Though artificial intelligence has immense potential, low digital literacy and poor infrastructure limit its application on smallholder farms. Still, experimental initiatives sponsored by businesses and non-governmental organizations show the cost-effectiveness of artificial intelligence, therefore promoting its possible general acceptance.

3. Genetic Enhancement and Breeding Technologies

Innovative genetics-based new breeding methods will enable dairy cows to generate more varied output. India used selective breeding historically to increase milk output. Improved germplasm access facilitates artificial insemination (AI) to be extensively applied, hence enhancing animal genetic quality. Many calves from genetically superior cows result from embroid transfer technology (ETT), therefore advancing genetic advancement. Reported in the Indian Journal of Animal Sciences [14] ETT considerably raised genetic progress and conception rates over conventional breeding techniques. Using DNA markers, genomic selection is the incredible capacity to forecast features including milk production, fat content, and disease resistance. Using genomic technology in crossbreeding initiatives has shown significant success in India in increasing milk output while preserving environmental tolerance and disease resistance. The limited acceptability of these technologies defines infrastructure problems, ignorance of native breeds, and the need of qualified labour. Projects of government such as the National Bovine Genomic Centre are encouraging research and the use of genomics in dairy breeding, therefore pointing a promising future for genetic improvement in Indian dairy systems.

4. Women-Centric Technological Interventions

Women make a major contribution to Indian dairy production particularly in rural areas where they mostly oversee animal care responsibilities. They help however sometimes they lack equipment, knowledge, and money. Targeting women, technology initiatives meant for them try to balance this disparity by providing ideas that cut labour, boost productivity, and encourage entrepreneurship, thereby addressing this inequality [15]. While motorized chaff cutters increase the effectiveness of fodder processing, portable and light-weight milking tools reduce physical labor. Thanks to projects at women-oriented skill development including those carried out by ICAR-CIWA [16] and several NGOs, thousands of women have become competent in milk testing, disease prevention, and value-added good manufacturing. Women hired by technologically savvy dairy enterprises engaged more than 60% in decision-making, according to a study published in the International Journal of Home Science. Apart from others, efforts in digital literacy and mobile apps provide women access cooperatives, real-time market prices, and veterinarian advice. Self-serve Groups (SHGs) and microcredit serve to increase financial inclusion, therefore raising their economic position. Case studies from states like Gujarat and Maharashtra show that in terms of profitability and animal treatment, women-led dairy cooperatives much surpass their male-dominated counterparts. Giving women technologies advances dairy output to raise inclusive rural development.

5. Infrastructure and Cold Chain Development

Maintaining the quality and safety of milk from production to consumption depends on robust infrastructure, especially with regard to cold chain systems. Great volume milk generated in India comes from far-off rural areas far from consumer centres in cities. Often the effect of poor refrigeration equipment and transportation is milk degradation. Refrigerated vehicles, bulk milk coolers (BMCs), storage facilities at milk collecting sites all help to somewhat create the cold chain. Designed to significantly reduce spoilage and bacterial contamination, the National Dairy Plan Phase I comprised bulk milk chilling facilities spread across about 54,000

sites. Apart from fast and hygienic milk testing, weight-based digital transactions made possible by automated milk collecting units (AMCUs) serve to boost supply chain confidence and efficiency. The research indicates that running expenses and carbon emissions of off-grid facilities are much reduced by solar refrigeration systems [17]. Energy economy still suffers, last-mile connection suffers, and real-time monitoring suffers even with these advancements. Combined government projects, corporate alliances, and international organizations will help to improve cold chain infrastructure all throughout the nation. Increased storage capacity and better logistics will result from higher export opportunities and farmer income, hence lowering post-harvest losses.

6. Sustainability and Climate Resilience

The growth in dairy production has to complement environmental sustainability and opposition against climate change. The growing industry sharply raises greenhouse gas emissions, land degradation, and water consumption. Including sustainable projects is therefore not optional but rather necessary [18]. One among the approaches is the development of low resource consumption native breeds with improved environmental shock tolerance. Managers of controlled feeding systems, effective manure management techniques, and water-saving technologies will help to minimize the effect on the surroundings. Since they enable composting and produce electricity from animal waste, increasingly used biogas plants support circular agriculture. Examining climate-resilient dairy methods in semi-arid regions of India, this Agricultural Systems article found that farmers using adaptive technology reported 25% higher resilience during severe storms. Dietary formulations meant to reduce methane emissions and enhance fodder crops are developed in part by institutions such as NIANP and ICAR. Moreover, the combination of new techniques with conventional ecological knowledge improves sustainability. Programs focused at public awareness campaigns and carbon credit incentives help to modify behaviour. Constant government backing, research money, local community and stakeholder cooperation projects define the evolution of climate-resilient dairy systems.

7. Conclusion

The Indian dairy company is dramatically changing driven by the mix of modern technology, including precision farming, digital automation, artificial intelligence, and genetic engineering. These techniques create great chances to increase production, lower running inefficiencies, and improve animal well-being. Moreover, inclusive policies ensure that technology advancements have more general socioeconomic benefits—especially those targeted to empower rural women and smallholder farmers. Among other things, automated milk collecting systems and cold chain systems serve to increase access and openness of infrastructure. Moreover, since climate change gets more intense, long-term viability depends simply on strong breeds and environmentally appropriate dairy methods. Notwithstanding these developments, limited digital literacy, high starting expenses, and infrastructure gaps, most especially in rural areas, still impede more general acceptance. Dealing with these difficulties calls for government agency, research institution, company, and dairy cooperative collaboration. Public-private partnerships, skill development programs, and legislative incentives will define exactly how these concepts are applied among the many dairy companies all throughout India. India should optimize technology by means of a targeted and all-encompassing approach guaranteeing food security, raise farmer income, and launch worldwide talks on fair and sustainable dairy production.

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